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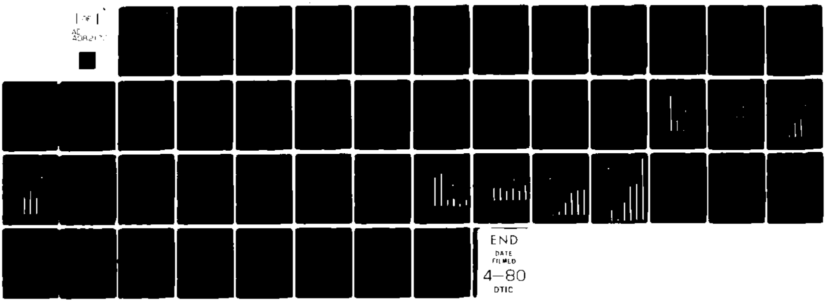

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the experimental results of studies undertaken to test the utility of steady state average evoked potentials (AEP) to measure the difficulty level of a tracking task. Transient and steady state AEPs were described with a brief summary of their use to study cognition and visual system function.

The first experiment showed an enhanced steady state AEP amplitude at only

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one stimulus frequency between 36 Hz and 66 Hz. This supported previous findings and also found that the effect resulted from sine wave modulated stimuli and not stroboscopic stimuli.

The second study tested the effects of three levels of tracking difficulty upon the amplitude and phase lag of the steady state AEP to 14 Hz and the subjects' peak response frequency between 42 Hz and 58 Hz. The phase lag of the high frequency AEP became longer with increased difficulty levels of the tracking task. The medium and high frequency AEP displayed different amplitude and phase characteristics indicating that they were derived from separate cortical sources.

The third experiment was designed to examine effects due to differential involvement of the cerebral hemispheres and the subjects' tracking experience at the different levels of tracking difficulty. Neither of the AEP measures were significantly influenced by these variables.

Possible application of these results as well as suggestions for future research were discussed.

AFOSR-TR- 80-0210

STEADY STATE EVOKED RESPONSES AS A MEASURE OF TRACKING DIFFICULTY

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Final Report for AFOSR Contract F49620-79-C-0156

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The assessment of human work load is crucial to the design and efficient operation of contempory systems. The man-machine interface is of the utmost importance with today's highly complex machine systems. Traditionally, behavioral measures have been used to gauge the effectiveness of a design or the degree of difficulty of a task. If behavior, as measured by reaction time for example, deteriorated then the design or task was adjusted to maximize the operator's performance. One difficulty with this approach is that the measurement itself often interferes with the task or adds to the work load of the operator. This contamination of the task by the measuring instrument must be kept in mind and controlled as much as possible. Obviously this limits the use of many experimental procedures in real life situations since they might interfere with an ongoing activity and lead to disastrous consequences. A method of work load assessment which does not itself add to the task difficulty and also which can be used in operational settings is needed.

Recent advances in human electrophysiology may be useful in overcoming some of the disadvantages of behavioral measures in assessing work load. Techniques utilizing average evoked potentials (AEP) seem to be especially promising. Since the brain is the organ which receives sensory information, processess it and initiates behavioral responses one should be able to utilize the brain's own activity to test the level of involvement in a task as well as to be able to compare one situation with another. Methods utilizing AEPs could be applied to experimental as well as operational situations since the electroencephalograph (EEG) is always present. The purpose of this project is to test a methodology which, if successful, will permit the noninvasive assessment of certain kinds of work load at both design and operational stages of the system.

Transient AEPs

Transient AEPs have been found to be useful tools in the study of human cognition. With this method individual stimuli are presented to the subject which require some type of cognitive processing. Several seconds lapse between stimuli allowing the nervous system to recover from the effects of the preceding event. Typically, twenty to one hundred stimuli are presented to the subject and the subject's brain responses to these stimuli are averaged together to form the AEP. Correlations are sought between the cognitive processes and segments of the associated AEP which is characterized by several deflections of variable amplitude and latency. These amplitude and latency measures are typically used to quantify the response. One reliable finding is that a late positive component, the so called P300, has been found to be associated with a number of psychological processes: uncertainty resolution (Sutton, et. al., 1965), discrimination (Ritter, Simson, and Vaughan, 1972), task complexity (Poon, Thompson, and Marsh, 1976), decision making (Rohrbaugh, Donchin, and Eriksen, 1974; Squires, K. et. al., 1977). See Donchin, Ritter, and McCallum (1978) for a current review. A common approach to studying the electrophysiology of these attention and work load processes is to vary the focus of attention or the level of load on the subject and assess changes in the amplitude and latency of P300.

A second method using transient AEPs to study attention, task difficulty and work load; one especially useful in situations where the primary task is not amenable to transient AEPs, utilizes a secondary task which uses discrete stimuli. AEPs are collected in response to the secondary task stimuli and some aspect of the AEP is used as an index of the level of attention or work load of the primary task. Many operational situations fit into this category because they do not involve discrete stimuli that can be used to provide an AEP, this is especially

true in the case of work load assessment. The use of a secondary task presents problems because it requires that some of the brain's capacity be assigned to processing this secondary information and thereby possibly detracting from the performance of the primary task. Donchin's group (Wickens, Isreal, and Donchin, 1977; Isreal, Wickens and Donchin, 1978) has measured the P300 of the AEPs to the target ("odd-ball") stimuli at several levels of difficulty of a primary tracking task. They reported that "first order" effects on the P300 were not useful as an index of work load. That is, the amplitude of P300 "declined percipitously as soon as the tracking task was imposed" making it necessary to analyze the sequence effects due to the ordering of the target stimuli. This paradigm, while useful, does not lend itself to rapid straightforward analysis and also may itself interfere with the performance of the primary task.

Steady State AEPs

Another method of eliciting responses from the brain is by providing a continuous stimulus such as a flickering light. This method is much like that used in electronics in which a signal is applied to a circuit and the relationship between the output signal and the input signal is used to characterize the circuit. To avoid the transient-like AEPs from the first few stimuli, the AEPs are collected only after the nervous system has reached a steady state condition following several seconds of stimulation. The amplitude, frequency and phase features of these sinusoidal AEPs are the typically measured characteristics. The frequency of the AEP follows that of the stimulus with the added feature of harmonics. The amplitude of these AEPs vary as a function of certain characteristics of the nervous system. As stimulus frequency is varied from 2 Hz to 100 Hz amplitude maxima are found in three regions. The lower range, which has the largest amplitude of the three, is centered about 10 Hz (the common alpha wave frequency), the middle frequency component and second in size is centered in the 15 Hz to

18 Hz range while the high frequency component and smallest amplitude of the three is in the area of 50 Hz (Regan, 1977a).

Steady state AEPs have been extensively used in two areas. In the first, spectral sensitivity, depth perception, spatial frequency and other aspects of visual system function have been studied (Regan, 1977a). Secondly, they have been used to detect neurological pathologies of the visual system, ex. ambliopia, multiple sclerosis and other disease states (Regan, 1977b).

Regan (1977b) has stated that steady state AEPs are probably not useful for studying cognitive processes. This is no doubt due to the requirement of rapidly repeated stimuli needed to elicit the steady state AEPs. The rate of stimulation would seem to exclude the presentation of cognitive stimuli and the retrieval of meaningful electrophysiological responses. However, it is possible to use the rapidly flickering stimuli to test the degree of involvement of central processes in a task. Since the human brain has limited processing capacity (Shiffrin, McKay, and Shaffer, 1976) increased resource utilization by the primary cognitive task should decrease the resources available for processing the background steady state information. If this is the case there should be changes in the steady state AEPs which are related to the subject's work load or task difficulty. If the continuous steady state stimulus is evaluated during the time that a subject is processing cognitive information one should see a detrimental effect upon the steady state AEP since processing resources would be directed to the cognitive task and away from the steady state stimuli. By using this technique steady state AEPs would provide useful information about the degree of central involvement in a particular task.

Unpublished results from the USAF-ASEE Summer Faculty Research Program of a study using a memory-scan task (Sternberg, 1969) and three rates of flicker in the low range (3.5, 5 and 7 Hz) support this hypothesis (Wilson and O'Donnell, 1978).

Individual numbers were tachistoscopically projected on a continuously flickering background using the memory-scan paradigm with memory set sizes of 1, 4 and 8 numbers. The RT and P300 data supported the findings of previous reports, indicating that the procedures used produced different levels of task difficulty. Steady state AEPs were collected during the 750 msec. that the subjects were processing the information. Preliminary results show that the Fourier analysis of the resultant steady state AEPs exhibited a decrease in the power of the EEG in the frequency bands related to the steady state stimulus in those conditions in which the subjects were also presented with transient stimuli as compared to those trials with flicker only. Further, these tentative results showed that as the memory set size increased there was a related decrease in the spectral power of the steady state AEPs. Steady state AEPs were not only decreased by a primary cognitive task but the degree of reduction was a function of the level of difficulty of the primary task. The utility of the steady state AEP is obvious since it discriminates between times when a person is or is not performing a task and more importantly, it can be used to monitor levels of task difficulty. Since the AEPs can be continuously monitored they provide a running index of operator involvement in the primary task. Although these preliminary data do not show it, steady state AEPs may be useful in determining an individual operator's capacity and also yield a measure of how close he is to reaching it at any moment.

Since the stimulus rates used in the above study produced noticable flicker it is necessary to examine this phenomena at higher rates of stimulation which are above the critical flicker frequency. If these results were found to hold at the high range of stimulation (around 50 Hz) then a truly noninvasive measure of cognitive involvement or work load would be available. The effects of the high frequency stimuli should be tested in a situation involving a different type of

cognitive processing and one which is also more closely related to operational tasks. Replication of these results in a visual tracking task would provide a better test of the utility of this paradigm in an operational setting as well as providing a further test of the utility of steady state AEPs in cognitive research.

Positive results with high rates of stimulation will permit the assessment of central involvement in a task and the assessment of the level of work load in most operational situations. It would be noninvasive and thereby not require the subject to divert attention and resources to the measuring instrument and away from the primary task or tasks. This method of assessment also has the advantage of speed, since steady state AEPs can be collected very rapidly permitting quick and continual assessment. The speed aspect is very important in many situations, especially those in a rapidly changing environment.

Three studies were performed to test the utility of steady state AEP amplitude and phase lag as measures of tracking difficulty. The research proposed in the original contract was completed and two additional studies were performed, one prior to and the other subsequent to the original research. The first study was necessary to provide parametric data about the individual nature of the high frequency response. The second study was suggested, in part, by the results of the original study and extended the research into the area of cerebral hemisphere lateralization and differences between accomplished and novice tracking subjects. Due to the cooperation of the personnel at Wright-Patterson AFB where the data was collected and the use of the same equipment and similar procedures in all three experiments it was possible to complete all three studies in the time alloted and within the budget of the original contract.

Experiment One: High-frequency steady state AEP amplitude as a function of stimulus frequency and stimulus waveform

It is known that a well-formed and reliable steady state evoked response can be obtained at frequencies above the CFF point (Spekreijse, 1966; Regan, 1972). These findings suggest that the human visual system may show temporal frequency sensitivities to particular kinds of stimulation. Further, Regan (1972) mentions in a footnote that individual subjects showed different peak frequencies within these maxima. However, the commonly presented figure representing the high-frequency component is based upon two or three subjects, and represents grouped data. Regan also speculates that the peak frequency observed by him, at approximately 48 hertz, may be influenced by the fact that his subjects were Europeans, who were typically exposed to 50 hertz electrical current. He suggests that the peak frequency might be different in areas utilizing 60 hertz electrical systems.

Obviously, there is need to define the ranges of peak sensitivities found in humans in more detail than is presently available in the literature. One purpose of this study was to collect steady state AEPs from several subjects in the high frequency range so that between-subject variability could be estimated, and so that decisions concerning the appropriate methodology for utilizing steady state AEPs in subsequent experiments could be defined.

An additional question with regard to steady state AEPs is the importance of the type of light source used, and specifically the waveform of the stimulus. Most studies in the high frequency ranges have used sine wave modulated light (Regan, 1968,a; Spekreijse, 1966). However, other forms of high frequency stimulation, such as stroboscopic light, are available. It is possible that such stimulation could be more efficient in the high frequency ranges. The relationship between steady state AEPs and the type of stimuli is of considerable theoretical importance. Since the

challenge to the visual system introduced by sine wave modulated light as opposed to pulse light is considerably different, the temporal resolution characteristics of the visual system would be expected to influence the final form of this response, it may be possible to infer a great deal about the efficiency of the visual system with particular kinds of stimulation.

A final question of interest concerns the appropriate location of electrodes for obtaining steady state evoked responses. It is well established that an occipital lead is appropriate for studying basic functioning of the visual system and for investigating and detecting certain pathological states (Regan, 1977a). The expanding range of possible applications for this technique raise other questions concerning appropriate sites of electrode placement. In many cases, interactions with cognitive activity would suggest that parietal or central sites might be appropriate. There is little data on the steady state AEP from these regions. For this reason, steady state AEPs were recorded from occipital, parietal, and central midline sites in order to permit their comparison, and to see if reliable steady state AEPs could be obtained from central regions of the human scalp.

METHODS

Six adults, three female and three male, with normal or corrected-to-normal vision served as subjects. Subjects viewed the stimulus setup from a distance of 81.3 centimeters. Sine wave modulated light was produced by two horizontal fluorescent tubes, 23.5 centimeters long and 12.1 centimeters apart. The lamps were driven simultaneously by a Scientific Prototype tachistoscope control, Model GB, modified so that its lamp intensity output could be modulated from an external oscillator. The space averaged luminous of the stimulus, measured from 81.3 cm in front of the fluorescent tubes was 17.3 fL at peak, with a modulation depth of 32 percent. For the stroboscopic stimulation, a GRASS Model PS22 photo stimulator

was used. The face of the strobe light was 13.3 centimeters in diameter, with an average intensity of 4.8×10^3 fL.

Stimuli were presented at 2 hertz intervals beginning with 36 hertz and ending at 66 hertz. Because of artifacts, probably related to 60 hertz activity, three frequencies were omitted from the data collection; 40 hertz, 48 hertz, and 60 hertz. At these frequencies, stimulation appeared erratic and steady state evoked responses from subjects were inconsistent and uncleared. Accuracy of the stimulus frequency was monitored continuously on a Tektronix Model DC 503 Universal Counter. The order of presentation of the various frequencies was randomized for each subject. The first 30 sec. of each record was not used in order to allow a steady state condition to be achieved by the subject. Subjects were instructed to fixate on a dot located at the center of each type of stimulus. However, no specific electro-oculogram (EOG) or other eye movement monitor was used to assure fixation.

EEG was recorded from Oz, Pz, and Cz sites, using the 10-20 international electrode system (Jasper, 1958). One mastoid was used for reference, and the other as a ground. Beckman silver/silver chloride electrodes were used. Electrode resistances were 5K ohms or less. Grass Model P511AC amplifiers with high input impedance probes were used to identify the EEG. The amplifier filters were set at 1/2 amplitude for 3.0 hertz and 300 hertz, 60 hertz filters were not used. A Nicolet Model CA 1000 was used to average the data. Each channel contained 256 data points, with a sweep epoch of 61.2 milliseconds. Each AEP consisted of the average of 100 samples, triggered on the first stimulus presentation or oscillation after completion of data collection for the previous sample. Amplitude values were recorded manually, permanent records were provided by X-Y recorder.

The subjects were given short breaks between stimulus conditions with a longer break given in the middle of the testing session. Room lighting was extinguished during the actual stimulation, and was turned on during the break.

RESULTS

AEP amplitudes were calculated by measuring two or three peak to trough values from each AEP depending on the number of complete cycles in the averaged epoch. These individual measures were then averaged together, and this value was used as the amplitude measure for the AEP. Harmonic frequencies sometimes appeared in the subject's evoked responses. These were ignored, and only major components which could clearly be identified were used to calculate average amplitude.

In Figure 1, mean occipital, parietal, and vertex amplitudes are shown as a function of stimulus frequency of the sine wave modulated light. An overall decline in amplitude with increasing stimulus frequency is evident for all electrode sites. This decline, however, is not monotonic. Amplitudes between 50 and 56 hertz show obvious enhancement. Repeated measures analyses of variance revealed a significant affect due to stimulus frequency ($F = 4.1$, $df = 11/55$, $p < .001$). The enhanced amplitude between 50 and 56 hertz is significant, as indicated by trend analysis, which revealed that the linear ($F = 7.0$, $df = 1/5$, $p < .05$), cubic ($F = 6.5$, $df = 1/5$, $p < .05$), quartic ($F = 16.08$, $df = 1/5$, $p < .01$) components were significant. The peak amplitude range across subjects varied from 50 hertz to 56 hertz, with the subjects spread across this range; 50 hertz -- 1 S, 52 hertz -- 3 Ss, 54 hertz -- 1 S, and 56 hertz -- 1 S.

Data from two individual subjects are shown graphically in Figures 2 and 3. Each subject produced a definite peak response at a particular frequency. For one subject, this frequency was 50 hertz, and for the other it was 54 hertz. All subjects produced similar peaks. Considering the six subjects, the peak occipital amplitude averaged 2.5 microvolts larger than the amplitude found at the frequency just below that of the peak itself.

The grouped data for stroboscopic stimuli are presented in Figure 4. The same linear decrease in steady state AEP amplitude as stimulus frequency increased

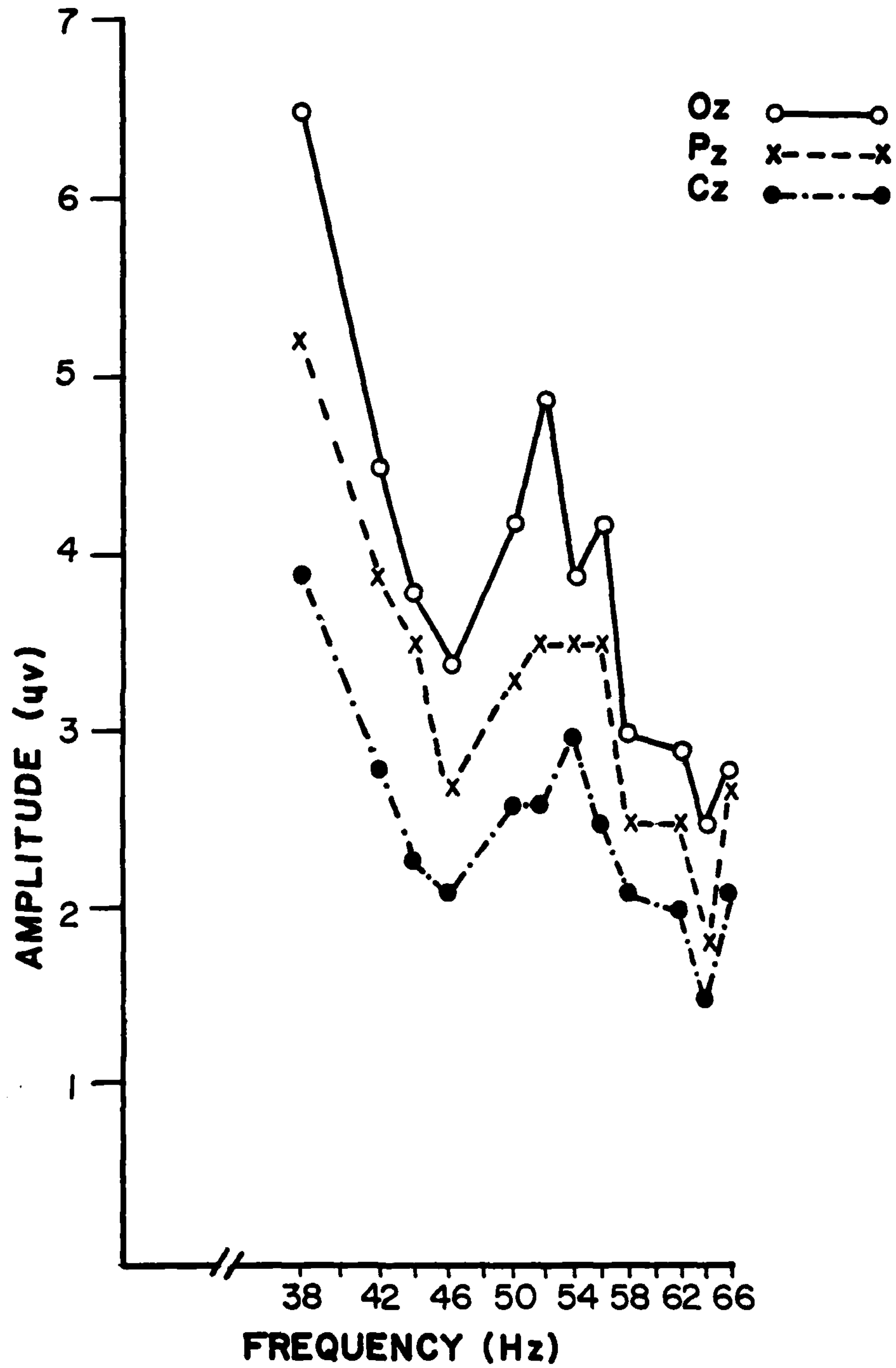


Figure 1. Mean AEP amplitudes derived from sine wave modulated stimuli as a function of frequency.

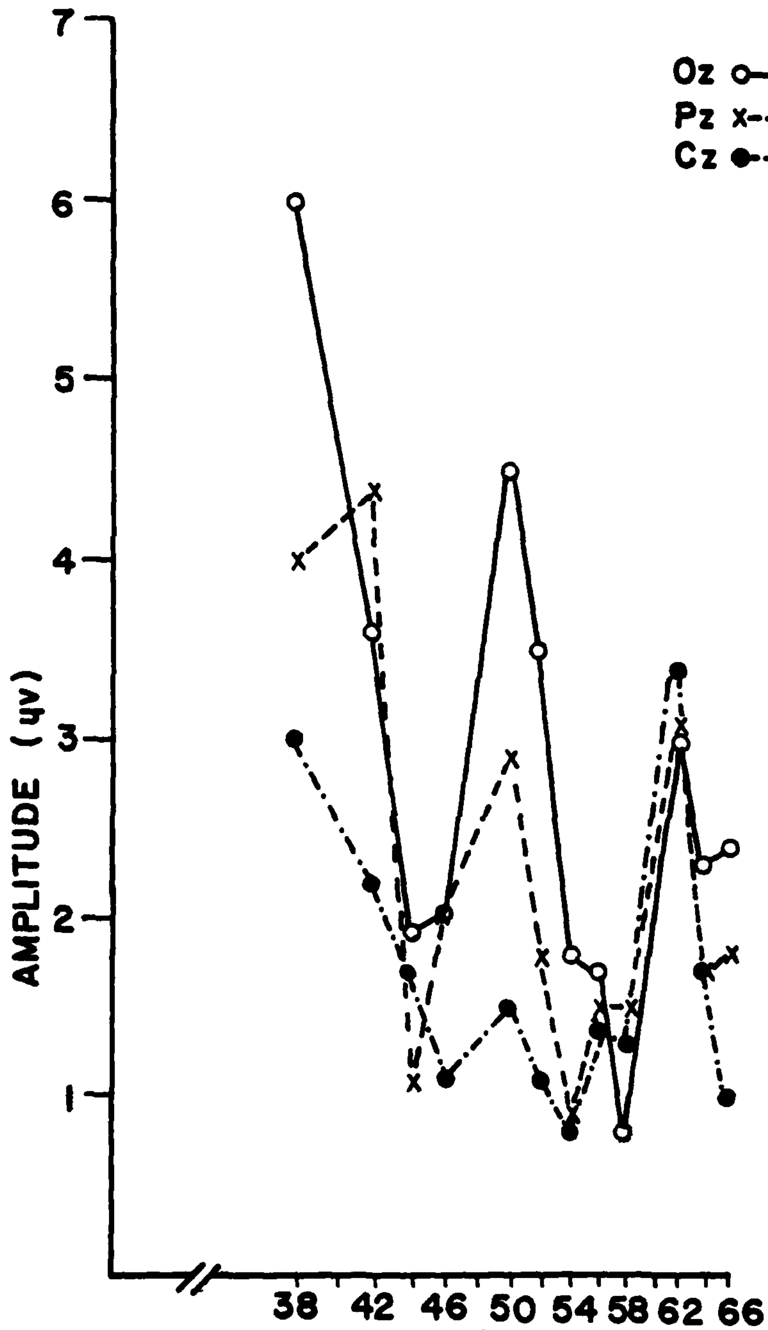


Figure 2. Sine wave generated AEP amplitudes for subject 04 as a function of stimulus frequency. Note the amplitude peak at 50 Hz.

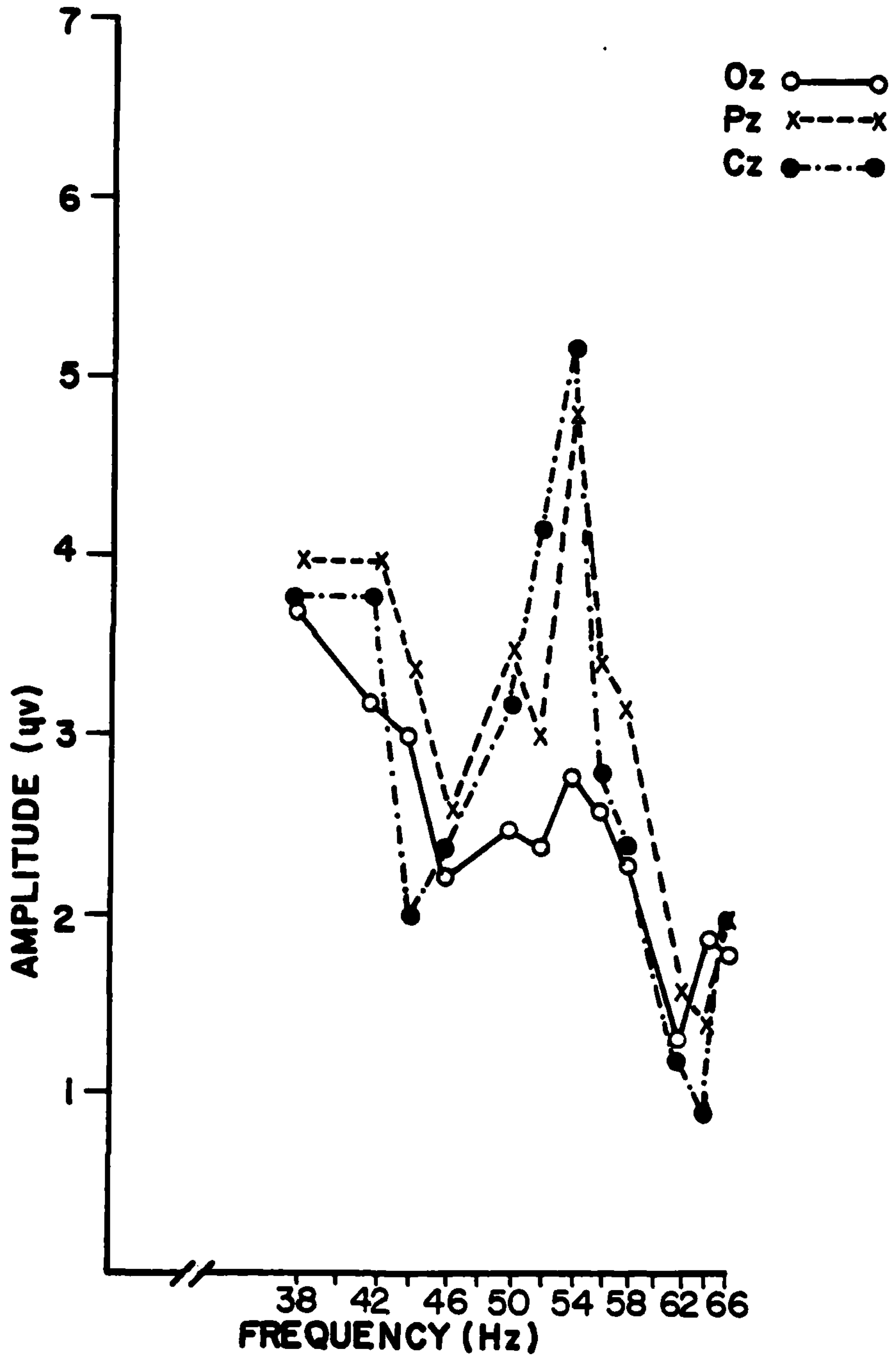


Figure 3. Sine wave generated AEP amplitudes for subject 06 as a function of stimulus frequency. Note the amplitude peak at 54 Hz.

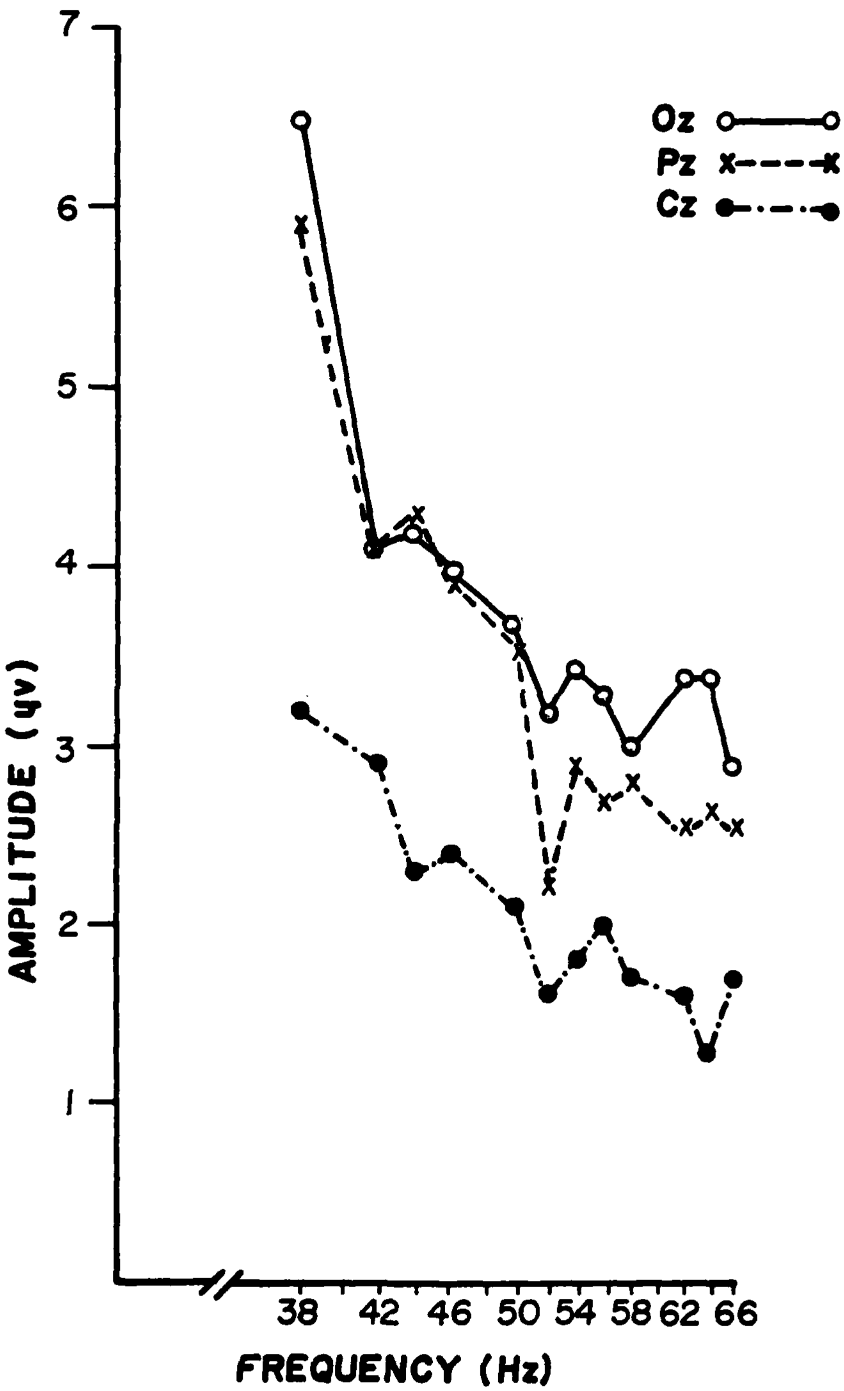


Figure 4. Mean AEP amplitude derived from strobe stimuli as a function of frequency.

that was found for the sine wave data is evident here. However, there is no enhancement of amplitude anywhere in this frequency band similar to that found with sine wave modulated light stimulation. Repeated measures of analysis of variance showed a significant affect due to stimulus frequency ($F = 6.16$, $df = 11/55$, $p < .001$). Trend analysis revealed a significant affect due to the linear component ($F = 12.49$, $df = 1/5$, $p < .02$). The quadratic component was large but not significant at the 5% level ($F = 5.9$, $df = 1/5$, $p < .059$).

With respect to electrode sites, AEP amplitudes declined generally from posterior to anterior, as one would expect. However, none of these differences were statistically significant for either type of stimulus. In some subjects, as illustrated in Figures 3 and 4, the parietal AEPs sometimes were seen to be larger than the occipital AEP. Thus, although generally larger responses are obtained from the occipital derivation, it is clear that robust responses can be obtained from more anterior locations.

Since female subjects characteristically produce larger amplitude transient AEPs than males (Rodin et. al., 1965) an analysis of variance was performed to test for this difference in the steady state AEP data. No significant difference was found for either the sine wave or strobe data due to the subject's sex.

DISCUSSION

These data confirm the previous reports which suggest that there are individual differences in the peak amplitude responses to high frequency stimuli. Further, characteristics of these differences across a small sample of subjects can be defined. In the present study, there was a 6 hertz range in the point of peak sensitivity between subjects in response to sine wave modulated stimulation, in the band between 38 and 66 hertz. The enhancement of steady state AEP amplitude to sine wave stimulation at a particular frequency between 50 and 56 hertz was a prominent characteristic of each subject's data, as well as the grouped data. This

sensitivity of each individual to a particular temporal frequency is not quantitatively trivial, averaging a two-fold increase of amplitude from levels which it had previously reached. Further, the sensitivity appears to be very narrowly tuned to a specific temporal frequency. As can be seen in Figures 2 and 3, the peaks are extremely sharp and show clear definition.

From a procedural point of view, these results are extremely important. They indicate that in any attempt to utilize high frequency steady state evoked responses in applied settings, where grouped data may be used, it is important to determine the peak frequency for each subject. Subjects should then be tested at this peak frequency. If one stimulus frequency is used for all subjects, the interaction with individual sensitivity at particular peak frequencies could confound the results. By locating each subject's highest AEP amplitude frequency, these individual differences can be used to the advantage of the researcher.

The existence of peak temporal sensitivities in the visual system is intriguing from a theoretical viewpoint. Regan (1968) and Spekreijse (1966) first suggested such temporal frequency sensitivities. One could postulate that such frequencies represent optimal conditions for nervous system function, much as certain spatial frequencies are processed most efficiently by the visual system. It would be interesting to determine if human performance shows either optimization or interference by concurrence stimulation at these peak frequencies. The individual differences in peak sensitivity within this frequency range are also of considerable potential interest. It is necessary to determine whether such individual differences are correlated with any other performance.

The data in the present study, in contrast to Regan's (1968) data reveal all subjects showing peak frequencies at 50 hertz or above. Regan had speculated that the peak revealed by his subjects might be due to the existence of 50 hertz alternating current in Europe, and he questioned whether subjects continuously exposed to 60 hertz alternating current might show higher peaks. The present

results would tend to answer this speculation positively.

The lack of amplitude enhancement within this frequency range to stroboscopic stimulation is a new result. Clearly, the nervous system responds differently to sine wave modulated light than to stroboscopic light, showing amplitude peaks to the former and not to the latter. AEP differences between these two types of stimuli were not correlated with the subjective perception of flicker. Subjects reported approximately equal flicker perception with both stimuli. However, this lack of correlation is not surprising, since Regan (1968, b) has demonstrated a clear dissociation between AEP amplitude and subjectively perceived flicker.

Obviously, there are considerable differences between the two types of stimuli used in the present experiment. The stroboscopic stimulation produces an extremely high intensity, short duration (20 micro second) flash, followed by complete darkness for a much longer period of time. The sine wave modulated light, on the other hand, had a modulation depth of only 32% and its wave form literally described a sine wave. In spite of these rather significant differences, the absolute amplitudes of the AEPs to the two types of stimulation were approximately equal. Thus, the visual/cortical system is capable of resolving both types of stimulation. For some reason, however, the system responds with increased intensity to certain frequencies for the sine wave stimulation, and not for the strobe stimulus.

Experiment Two: High frequency steady state AEP amplitude and phase lag as a function of tracking difficulty

The purpose of this experiment was to test the utility of the amplitude and phase lag of the steady state AEP as measures of the level of tracking difficulty. If the brain has limited but divisible capabilities then it may be possible to use the steady state AEP as a measure of the residual capacity during a primary task of graded difficulty. As a task becomes increasingly difficult more of the brain's processing capacity will be utilized. It may then be possible to use the brain's response to an unrelated external stimulus as an indicator of the leftover performance capacity. By using visual stimuli of a frequency near critical flicker fusion which does not require the subject's attention, one would have a relatively noninvasive measure. The previous experiment demonstrated the necessity of finding each subject's peak frequency so as to not cancel out this effect by using one frequency for all subjects.

The previous experiment also demonstrated that steady state AEPs could be reliably recorded from parietal and central sites. This is significant since parietal and central AEPs have been found to be closely associated with cognitive behavior. Additionally, the tracking task used in this experiment involves visual input, cortical processing and motor output making it necessary to monitor occipital, parietal and central cortical areas in order to assess AEP associations with ongoing processes in these areas.

As Milner, Regan and Heron (1972) have pointed out, medium and high frequency responses have different anatomical loci, different color properties and intensity relationships. This would argue for the inclusion of medium frequency stimuli in the experimental design since one of these responses may be related to cortical capacity while the other may not. Also this would maintain continuity with an earlier study which found medium frequency steady state AEP amplitude changes as a

function of cognitive tas- difficulty (Wilson, 1979). By including medium frequency stimuli it will be possible to compare the effects of a cognitive task with that of the visuomotor tracking task used in the present experiment.

METHODS

Six adults, three female and three male, with normal or corrected-to-normal vision served as subjects. Three of these subjects had participated in the previous experiment. The equipment used to provide the sine wave stimuli in the previous experiment was used in this study. The flourescent tubes were mounted on the front of a Tektronix model 632 monitor. The light level from the sine wave stimuli in this configuration was 6.0 fL with a 32% modulation depth. Two rates of stimulation were used for each subject, a medium frequency rate of 14 Hz and a high frequency rate individually determined for each subject between 42 Hz and 58 Hz.

The tracking equipment consisted of a computer controlled cathode ray tube display which provided a horizontally moving cursor and a centrally located target. The rate of slew of the cursor was controlled by a 10-turn potentiometer. The subject manipulated a lightly loaded lever to control the position of the cursor to keep it on the target. This apparatus has been found to provide variable levels of difficulty which produce performance varying from error free to zero tracking (Elfner and O'Donnell, 1978).

EEG recordings were derived from Oz, Pz and Cz of the 10-20 International system (Jasper, 1958) referred to Mastoid. Beckman silver/silver chloride electrodes were used with electrode resistances of 5K ohms or less. Grass Model P511AC amplifiers equipped with high input impedance probes were used to amplify the EEG. The amplifier filters were set at ½ amplitude for 3.0 Hz and 300 Hz, 60 Hz filters were not used. The EEG and signals related to the flicker were recorded on a Vetter Model A FM tape recorder. A Digital Equipment Corporation

PDP8 (Lab-8) computer was used to average the data. Each channel consisted of 512 data points, sampled every millisecond for a sweep epoch of 511 msec. Each AEP consisted of 100 samples triggered at the highest point of the sine wave modulation. The AEPs were plotted, then amplitude and latency values were recorded with programs written in the laboratory (Wilson & Gregory, 1978). Two amplitude measures were made, one each from approximately 1/3 and 2/3 of the length of the epoch. These were averaged together and the average was used in the statistical analyses. Latencies of the first trough of the AEP were recorded.

Prior to recording the EEG each subject was given practice with the tracking apparatus. Three levels of difficulty were derived by finding the highest difficulty setting at which the subject could not keep the cursor on the screen for eight of ten one minute trials. The difficult level for each subject was 0.5 setting below the level above, a setting of 3.0 below this on the 10-turn potentiometer was the intermediate level and a setting of approximately 5.0 below was their easy level. These criteria were selected on the basis of subjective reports of the relative degree of difficulty.

The order of presentation of the three levels of tracking difficulty by the two stimulus flicker rates and flicker with no tracking was randomly determined. The subjects were given short rests between conditions with a longer break half way through the session.

RESULTS

The group average of the 14 Hz AEP amplitude data is presented in Figure 5. A precipitous drop in amplitude is seen as the recording site moves anterior. This effect as tested with a repeated measures analysis of variance is significant ($F = 9.41$, $df = 2/10$, $p < .005$). There was no significant difference due to tracking difficulty level. This is evident by inspection of the figure. Statistical analysis of the high frequency amplitudes showed no significant differences due to either electrode site or tracking difficulty level. Figure 6 shows the high

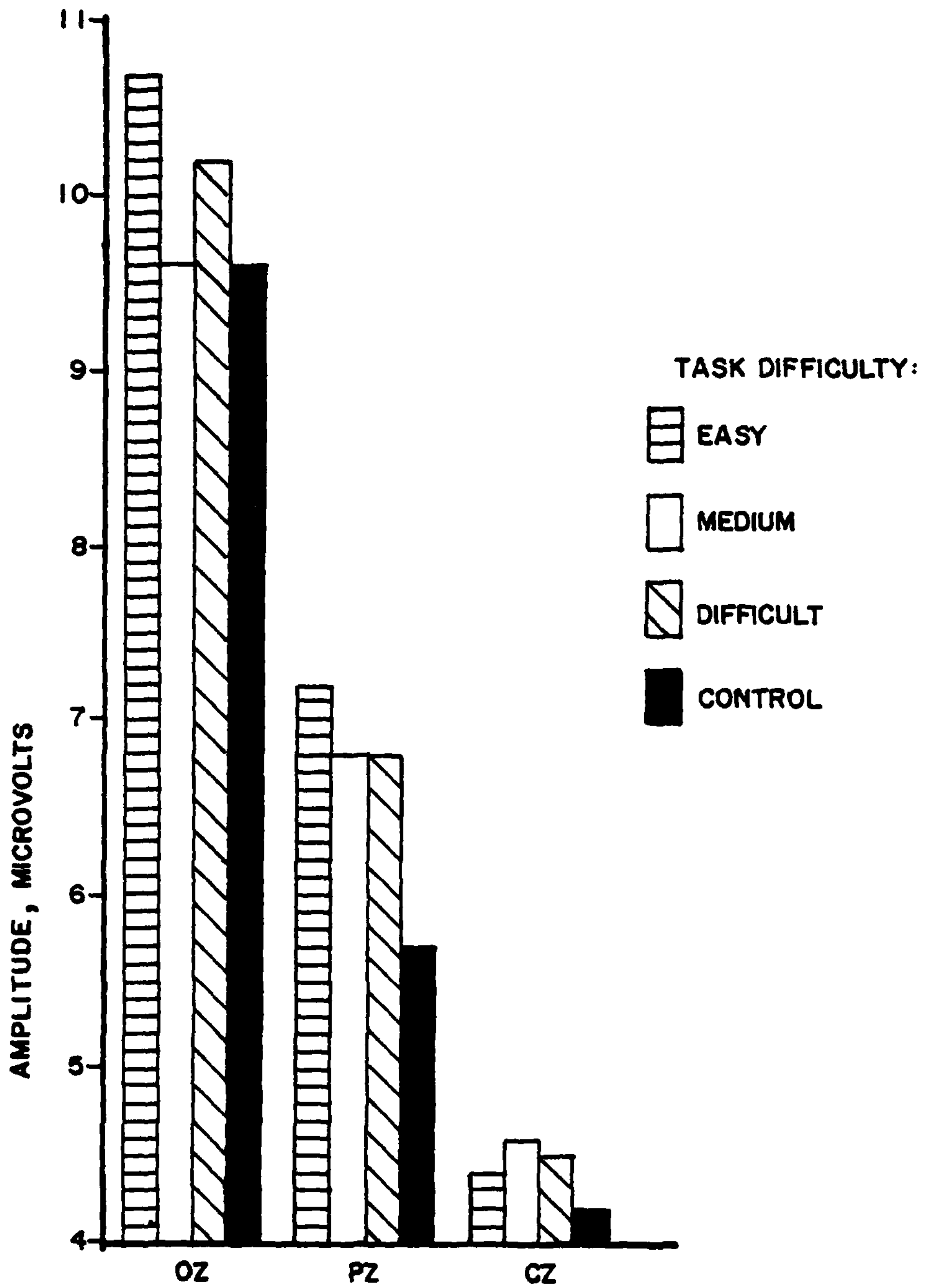


Figure 5. Mean AEP amplitudes from the medium frequency conditions. Note that the origin of the ordinate is not zero on the graph.

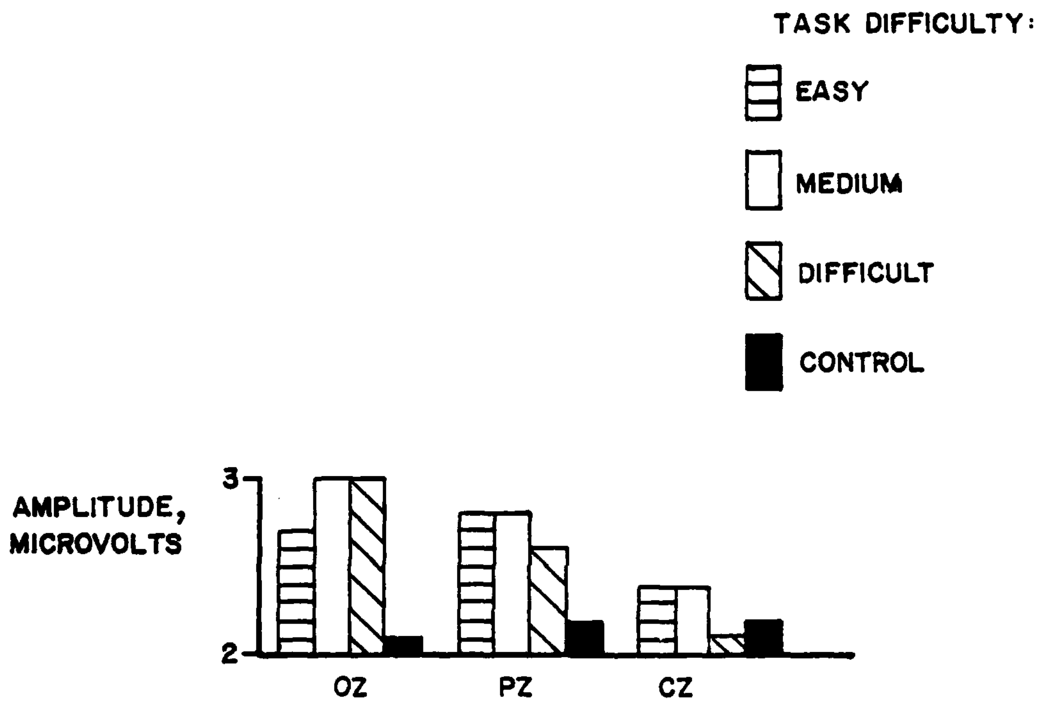


Figure 6. Mean AEP amplitudes from the high frequency conditions. Note that the Y-axis origin is not zero.

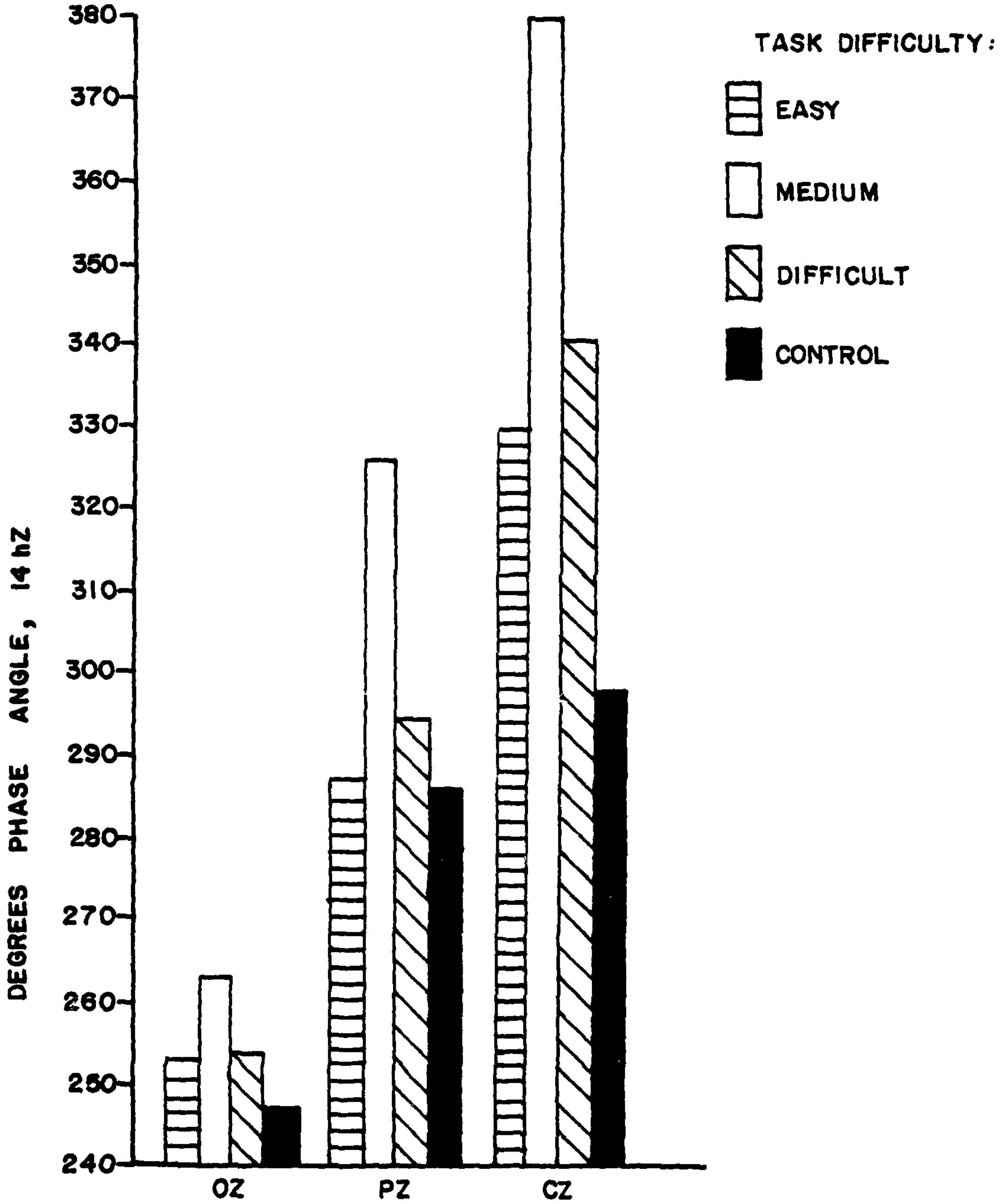


Figure 7. Average phase angle lag for the medium frequency conditions. The origin of the ordinate is not zero on the graph.

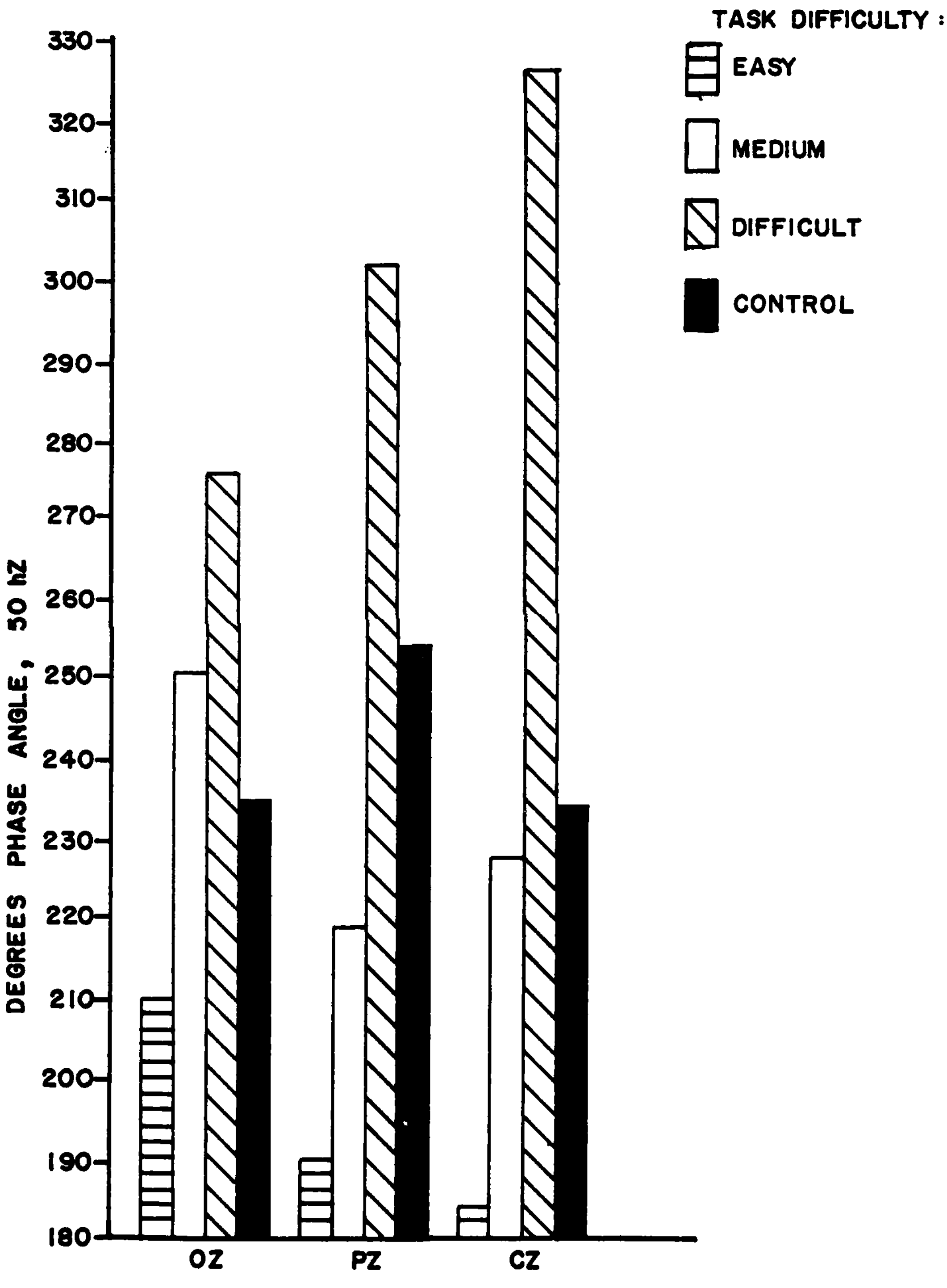


Figure 8. Mean phase angle lag for the high frequency data. The Y-axis origin is not zero on the graph.

frequency AEPs to be uniformly quite small across electrode sites and over the various tracking difficulty levels. The medium and high frequency responses show quite different effects when considering electrode location.

The medium frequency phase lag data are shown graphically in Figure 7. Again there is a statistically significant effect due to electrode site, more anterior sites producing greater amounts of phase lag ($F = 12.20$, $df = 2/10$, $p < .002$). While the medium tracking difficulty level was associated with greater phase lag at all three electrode sites the differences were not statistically significant. The high frequency phase lags were not significantly effected by electrode site (See Figure 8). However, the more difficult levels of the tracking task resulted in significantly larger phase lags in the AEPs ($F = 5.85$, $df = 2/10$, $p < .021$). As can be seen from the figure the easy tracking level resulted in the shortest phase lag at all electrode sites with the medium next and the difficult the largest. The control condition lags were intermediate. The medium and high frequency responses are again seen to differ when considering phase lags. The medium frequency response is effected by electrode site and not tracking difficulty level while the high frequency response is effected by tracking difficulty level but not electrode site.

Analyses were performed on the data to test for male-female effects. None of these were significant for either amplitude or lag for both medium and high frequency AEPs.

DISCUSSION

These data show that the phase lag of high frequency steady state AEPs are differentially influenced by the difficulty level of the primary tracking task. Change in transmission delay is in the predicted direction, that is, as the primary task becomes more difficult there is a greater lag of the AEPs to the background flicker. It may be that this added delay of the AEPs results from

fewer neural units being able to participate in processing the flicker information. More cortical units would necessarily be involved in the primary task and therefore unable to participate in the processing of the unrelated and relatively unimportant flicker stimuli. A second explanation is that the increased activity required by the primary task interferes with the efficient processing of the unrelated visual information from the background flicker. Shared pathways and cortical units would be engaged in the higher priority tracking task which may interfere with the processing of this secondary information by shunting it aside or to less efficient pathways. Other explanations could no doubt explain the data. The important factor at this point is that a significant delay in phase was found in this study. Replication and extension of these results should lead to the best explanation of these data. The exact relationship between phase lag and task difficulty needs to be further studied since the difficulty levels used in this experiment were based upon subjective judgements. More exact objective behavioral criteria should be applied to the primary task in future experiments.

The amplitude of the high frequency steady state AEP was not related to either tracking difficulty or electrode site. The amplitudes at all sites and tracking levels were quite small and relatively uniform. The amplitude of the high frequency response is independent of the AEP phase as well as site and difficulty level.

These results confirm Milner, Regan and Heron's (1972) conclusions that the medium and high frequency responses have separate origins and functions. The medium frequency data from the present study was effected only by electrode site and not tracking difficulty. Neither the amplitude nor the lag of the AEPs was related to the difficulty level of the primary task. Both of these measures were found to change with electrode site, the amplitudes became smaller and the lag became longer the further the distance from the occipital area. This would indicate that the medium frequency response is primarily visual in nature since amplitude and latency change as they are measured further from the visual area of the brain. The

high frequency response is of a different nature since its amplitude is small at all sites but the degree of phase lag increases as a function of the difficulty level of the tracking task not as a function of the distance from the occipital area. This system then must have a different function and possibly a different anatomical loci.

The lack of agreement with Wilson's (1979) unpublished data for the medium frequency response may be due to differences in primary tasks. The earlier study used verbal and spatial cognitive tasks which are different from the visuomotor tracking task of this experiment. Other procedural factors may also be responsible for the differences.

Experiment Three: High frequency steady state AEP amplitude and phase lag as a function of cerebral hemisphere, tracking experience and tracking difficulty

Cerebral cortical specialization of function is a well known phenomena. The cerebral hemispheres have been found to be differentially specialized; the left, in approximately 95% of the population, has the primary responsibility for language while the right specializes in spatial abilities. A great deal of evidence from the clinical and experimental literature supports these conclusions. This data includes studies showing changes in the electrical activity of the hemispheres with changes in the subjects' task from spatial to language and vise versa. The bulk of this data involves the relative amounts of two natural occurring rhythms, alpha and beta. The hemisphere most involved with a particular task shows lower alpha levels than the other hemisphere. This has been interpreted as a sign of the increased activity of the hemisphere responsible for a given task. (See Dimond and Beaumont, 1974 and Harnad, et. al., 1977). Since the tracking task used in the preceeding experiment involved visual-spatial abilities, right occipital and parietal areas, as well as the involvement of the left central motor area, right handed subjects, it is possible that the steady state AEPs may be differentially effected over these cortical regions. The mechanisms responsible for decreasing the alpha activity may well produce amplitude and/or phase lag changes in the steady state AEPs. Further, by locating electrodes over active cortical areas, rather than midline sites, more specific localization of phase lag effects could be possible.

Another area of interest with regard to the findings of the preceding experiment is the importance of prior training and practice with tracking. It is well known that performance on visual-motor tasks improves with practice. It is reasonable to assume that prior experience on this type of task effects not only performance but also brain activity that may be monitored by the steady state AEP.

The subjects who served in the second experiment were relatively naive with regard to tracking. A group of highly experienced trackers was available for participation in this experiment, permitting comparison of highly experienced and relatively naive subjects.

The purpose of this experiment was twofold; to test for hemisphere lateralization effects and to assess the effects of tracking practice on steady state AEPs.

METHODS

Six adults, four male and two female, with normal or corrected-to-normal vision served as subjects. Three of these subjects had extensive prior experience as trackers. They were members of a pool who daily performed in various tracking projects. One subject had two years experience, another one year and the third two months. The three relatively naive subjects had served in the second experiment.

The tracking and visual flicker apparatus was the same as that described in the previous experiment. The EEG recordings were made with the previously described equipment and procedures except that the following electrode sites were used: O1, O2, P3, P4, C3 and C4 of the 10-20 international system (Jasper, 1958). Linked mastoids were used as the reference for the active sites. The analysis procedures for averaging and measuring the steady state AEPs were also the same as those used previously.

The procedures previously used for selecting tracking difficulty levels were again applied. The order of presentation of experimental conditions was randomized for each subject. Short rest breaks were given between conditions with a longer break midway through the experiment.

Repeated measures analysis of variance was used to statistically analyze the data.

RESULTS

The average peak to peak amplitude data for the medium frequency AEPs is shown in Figure 9. There is a large drop in amplitude found between the occipital and the other two areas. These differences were significant ($F = 4.86$, $df = 5/25$, $p < .003$). Comparison of the data from the left and right hemispheres was not significant. Figure 10 graphically presents the high frequency grouped amplitude data. Again these amplitudes are much smaller than those to low frequency stimulation. Contrary to the results of the previous study a statistically significant amplitude effect due to electrode site was found ($F = 7.61$, $df = 5/25$, $p < .001$). The occipital data is larger than the parietal and central which are approximately the same. There was no significant difference between the data from the two hemispheres.

There were no significant differences due to either tracking experience or sex for the medium or high frequency amplitude data. Neither of these variables produced amplitude effects that were statistically significant.

The medium frequency phase lag data, illustrated in Figure 11, shows increasing delay from the parietal and central sites compared with the two occipital sites. These differences were significant ($F = 4.42$, $df = 5/25$, $p < .005$). Phase lag effects due to the difficulty level of the tracking task were not statistically significant. With regard to phase lag effects due to left and right hemispheres, there was again no significant differences.

Inspection of the high frequency phase lag data, Figure 12, does not show clear differences between electrode sites. However, the analysis of variance reported a significant effect due to electrode site ($F = 3.48$, $df = 5/25$, $p < .016$). Removal of the control data from the analysis eliminated this significant effect. ($F = 1.07$, $df = 5/25$, $p < .848$). Inspection of the graph shows that there is little difference between electrode sites, especially if one ignores the control condition

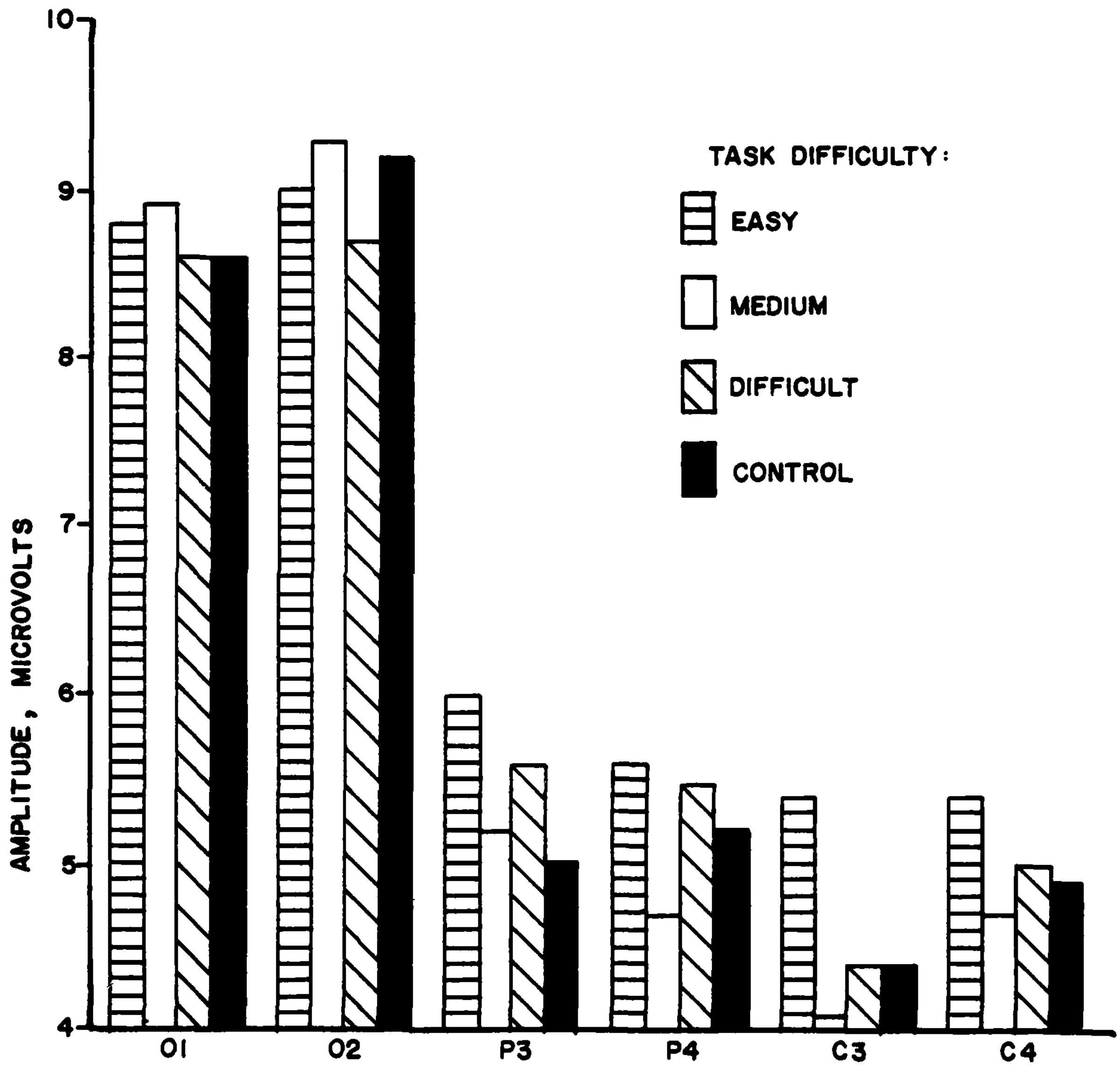


Figure 9. Mean AEP amplitudes for the medium frequency data as a function of electrode site and task difficulty. Note that the origin of the Y-axis is not zero.

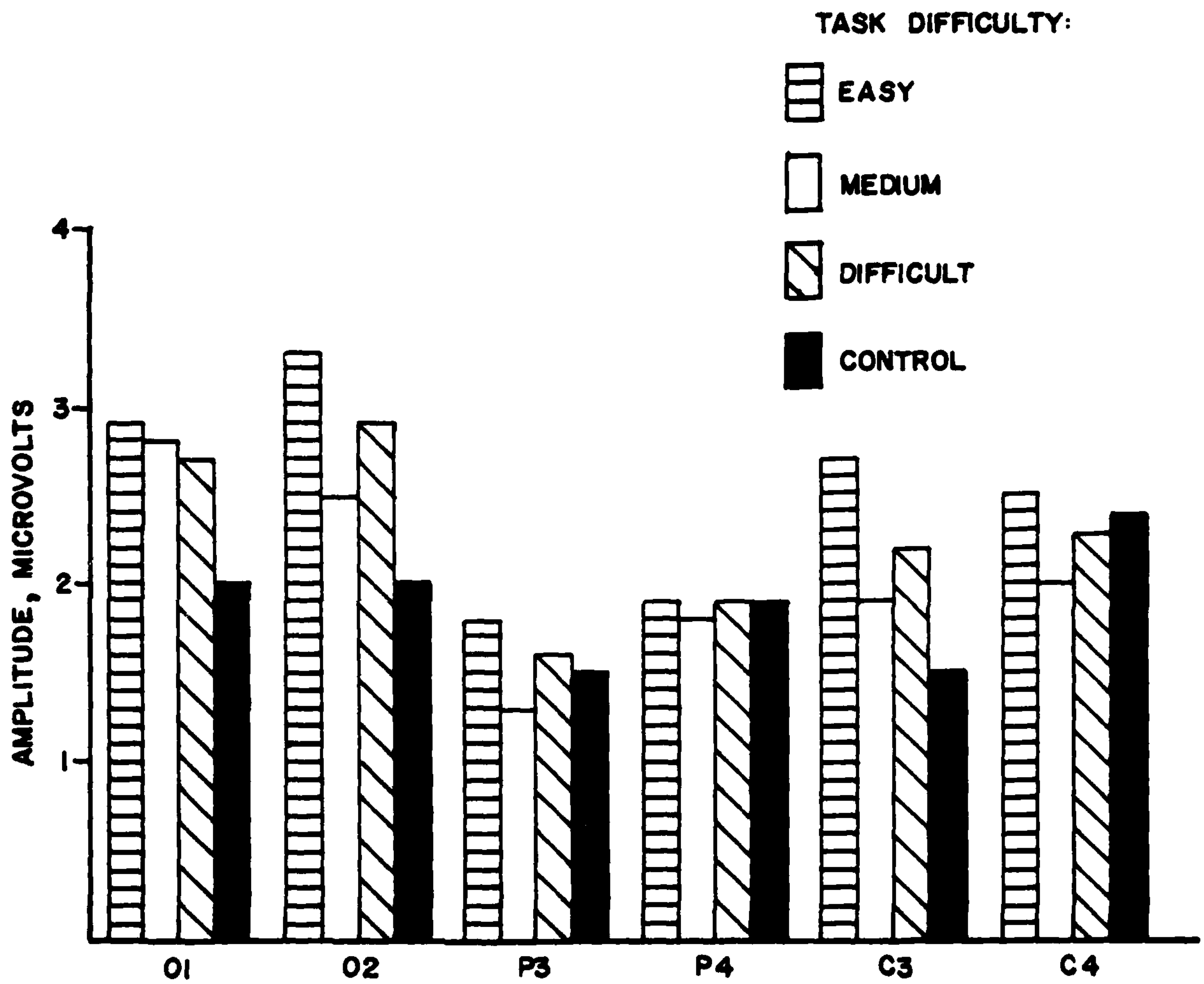


Figure 10. Mean AEP amplitudes for the high frequency data as a function of electrode site and task difficulty. The origin of the ordinate is not zero.

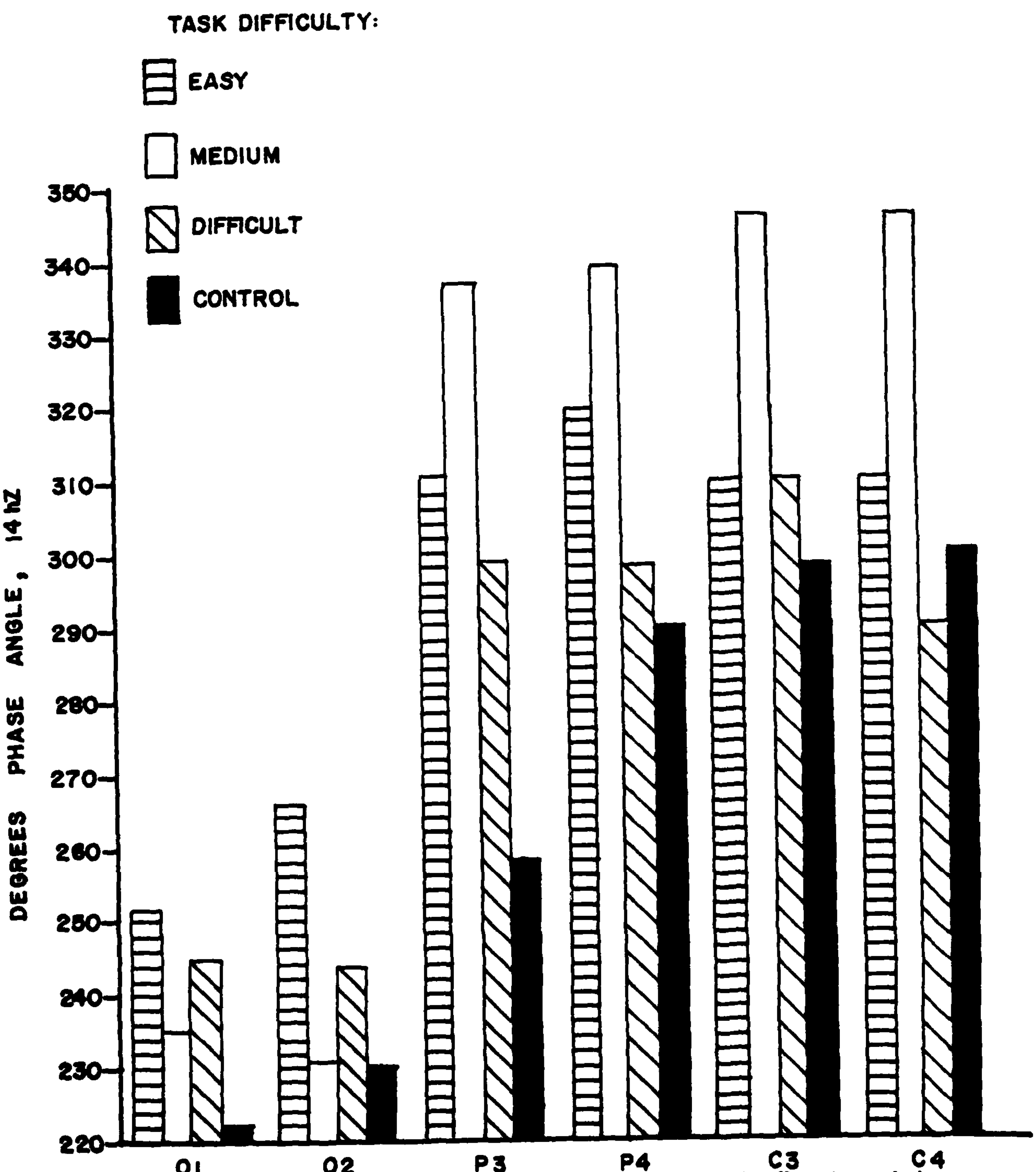
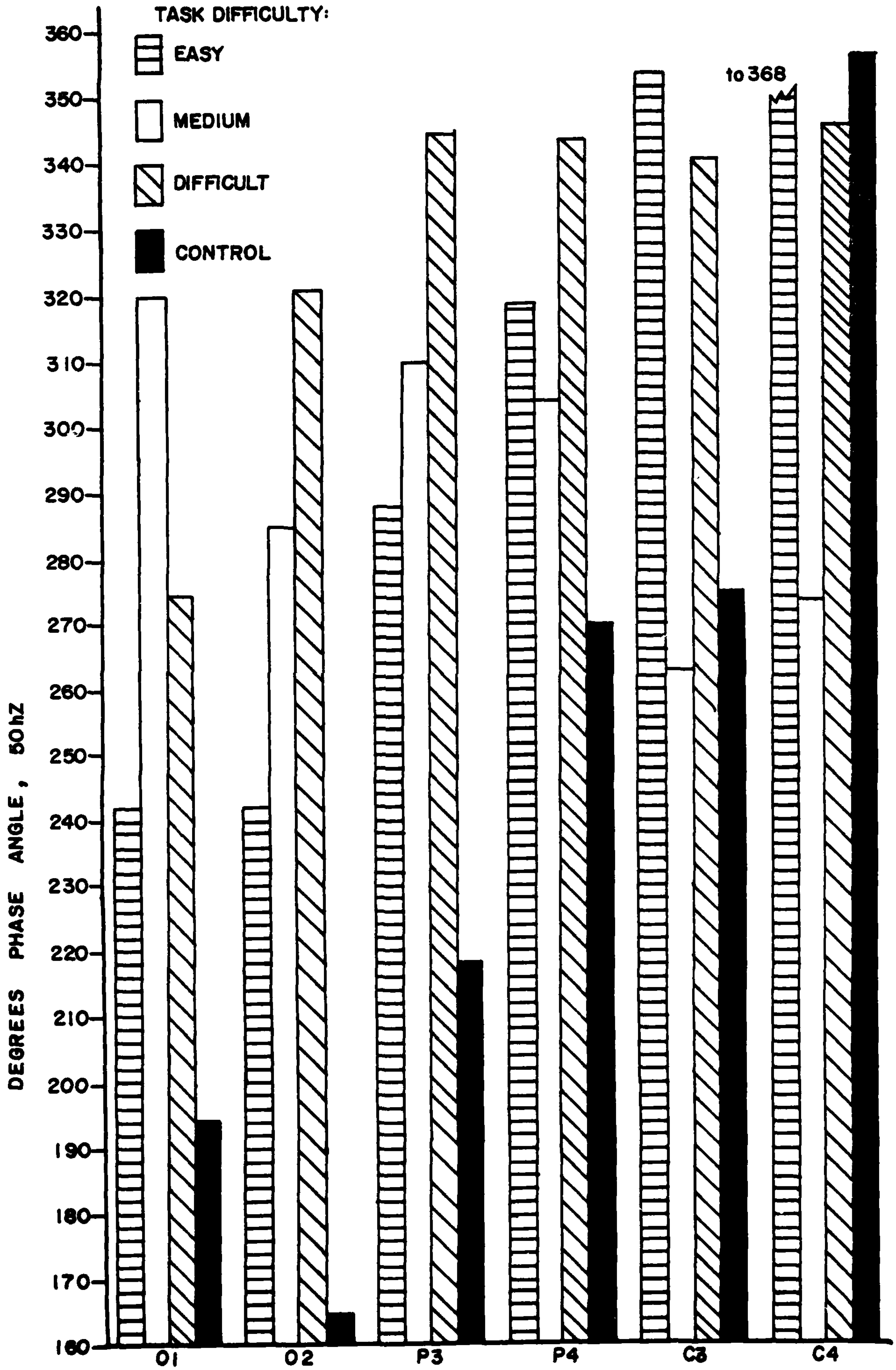


Figure 11. Average phase lag for the medium frequency data. The Y-axis origin is not zero on the graph.



[illegible] 10. Average high frequency phase lag. Note the nonzero origin.

data, flicker only with no tracking, which is itself not consistent. In contrast to the previous experiment no significant difference was found due to tracking difficulty level. The data presented in Figure 12 shows no consistent pattern of phase lag across electrode sites as a function of difficulty level. This data is obviously different from that of experiment two where the electrodes were positioned along the midline. Phase lag differences due to hemisphere effects were significant. ($F = 6.44$, $df = 1/5$, $p < .052$). Again, inspection of Figure 12 reveals a great degree of similarity between left and right electrode sites over each lobe except for the control condition which is again inconsistent and highly variable. A second analysis of this data excluding the control condition failed to reach significance ($F = 1.12$, $df = 1/5$, $p < .338$). There was no significant difference in the phase lag data due to either tracking experience or sex for the medium or high frequency conditions.

DISCUSSION

These data do not support the hypothesis that the steady state AEP can be used as a measure of hemisphere involvement in a tracking task. However, before ruling out the use of steady state AEPs to study hemisphere specialization the task used in the present study must be examined. Since the effect of this task upon the relative levels of alpha activity has not been studied the assumption that it differentially involves the left and right hemispheres must be examined. The task is of a visual, spatial nature, however, it is not clear if just the right hemisphere is involved in the task or if the left is also used. Additionally, internal verbal processes may accompany the performance of the task. The left motor cortex was used by our right handed subjects, however, several subjects also used the left hand to help control the lever or to steady the right hand. This would no doubt interfere with finding clear cut differences between hemispheres since both motor cortices would be active.

The data did not show significant differences between the AEPs of experienced and relatively novice trackers. This may be because the differences are too subtle or of such a nature that they can not be detected by changes in the steady state AEPs. Another possible explanation is that the performance level required by the tracking task used in this experiment was not sufficient to differentiate between the two groups. The task required tracking only in a single axis. While no measure was taken of actual performance the preliminary level selection procedures did not show a great deal of difference between the two groups. It is possible that different and/or more difficult visual-motor tasks may reveal AEP differences between novice and experienced levels of performance.

The one disturbing result is the lack of replication of the high frequency lag effect due to tracking difficulty level. Since the same apparatus and procedures were used in this experiment as in the second experiment, differences in the data are most likely not due to those factors. Different electrode sites were used. While located over the same lobes of the brain there are significant differences. The first study used sites on the midline, which record electrical activity from the medial areas of both hemispheres. The second study utilized sites several centimeters lateral to the midline which recorded activity from different cortical tissue than those located on the midline. Since the precise brain areas involved in tracking behavior and in processing the background visual information are not known it is difficult to decide which sites are relevant and which are not. It may be that the midline electrodes are over cortical tissue which participates in these operations. Also the midline sites may actually average electrical activity from the two hemispheres and derive a composite which is related to task difficulty level. Another explanation is that the results of the first study are spurious. However, it would seem that the best solution would be in the replication of these studies as well as carrying out new studies to test the reliability of the midline data in other situations.

The medium frequency data was again determined by the electrode site and not by tracking difficulty level. This was true for both amplitude and phase lag. Sex differences were not a significant factor in determining the amplitude or phase lag of the AEPs from either medium or high frequency background flicker stimulation.

SUMMARY

The results of these experiments demonstrate that the steady state AEP can be used to measure the level of tracking difficulty. The data from the second experiment show that the phase lag of the high frequency AEP was related to the level of tracking difficulty. Increasing the difficulty of the tracking task resulted in increased phase lag of the high frequency AEPs at all three midline electrode sites. Since the frequency of this stimulus produced little noticable flicker and did not require the attention of the subject it is a relatively non-invasive measure of task difficulty. If further studies find this to be a reliable effect then this procedure can be applied not only to work load and task difficulty situations but also used to monitor attention, fatigue and possibly cortical specialization of functions.

The use of this one procedure to monitor the level of cortical involvement in such diverse situations would have tremendous applied and theoretical advantages. This measure would permit comparisons between highly different tasks using a common scale. Theoretically, similarities between diverse situations could be found and used to find underlying common mechanisms. For example, do similar mechanisms underlie performance decrements due to fatigue and inattention? One additional advantage of this procedure is the speed at which data can be collected. Using a device similar to that developed by Regan (1977c) one can acquire phase lag and amplitude data within seconds of its occurrence.

Since this procedure requires only a flickering light source it can be used in many experimental paradigms. It will not add to the work load of the primary task nor interfere with many tasks. It can also be used with many types of apparatus. This would include those using visual displays as well as auditory and tactual modalities.

Recordings from each hemisphere in the third experiment did not replicate

the midline findings making further studies imperative to find out if the phenomena exists only at the midline or if the midline results are spurious. As mentioned in the discussion of the third experiment, there are several possible explanations for the discrepancy, including the difference in recording sites. The potential use of this technique in applied and theoretical situations necessitates further work in this area.

Future research should also more carefully examine the nature of the relationship between high frequency phase lag and task difficulty level. In the present research the exact levels of performance were not recorded. Behavioral data should be collected and tasks used which have more objective levels of task difficulty.

The results of the first study are also important and suggest further areas of research. It is very important to know that each subject has a frequency of maximal response. It is important then that future studies take this into consideration and do not use just one frequency of stimulation for all subjects thereby confounding their results. The existence of the peak frequency for each subject may mean that the presence of that frequency as background light may enhance or decrease a person's performance on a primary task. Another question is whether individuals with higher frequency peaks perform better or worse than people with a lower frequency peak. The lack of amplitude enhancement to strobe stimulations shows that the visual system can easily distinguish between these two stimulus types. The exact nature of this resolution is not known. Diamond (1979), using steady state AEPs, suggests that the visual system can detect temporal differences as short as 30 microseconds. Could the differences to sine wave and strobe stimuli be related to these temporal resolution mechanisms?

The differences found between medium and high frequency AEPs with regard to spatial distribution and tracking difficulty supports the work of Milner, Regan and Heron (1972). They reported that these two responses had different anatomical loci and also different functions with regard to color processing. The data from

the present studies also found anatomical and functional differences. The medium frequency AEP amplitude and phase lag seem to be specifically related to the visual area and visual functions. The high frequency AEP amplitude was relatively small at all electrode sites while the phase lag was effected by the level of task difficulty. Other relationships between the high frequency response and behavioral variables may be found as previously suggested. For example, Regan (1972) reported that all of his subjects showed peak frequencies below 50 Hz while the present data showed all peak frequencies to be 50 Hz or above. Regan speculated that the peak revealed by his subjects might be due to the existence of 50 Hz alternating current in Europe. Is it possible that exposure to a particular light frequency could have long term perceptual effects?

With regard to the use of steady state AEPs to study hemisphere specialization it seems necessary to use tasks that are known to differentially involve the hemispheres. If one can demonstrate a relationship between steady state AEPs and known hemisphere involvement then a better case can be made to use the AEP as a measure of lateralization. Otherwise, negative results may be found because the tasks being used do not differentially involve the hemispheres rather than due to the inability of the AEP to detect such differences. If the high frequency phase lag results reported here are found to be dependable then it is reasonable to predict that this measure would be useful in determining the degree of hemisphere involvement in various tasks.

It should be noted that the lack of positive findings for tracking experience and sex differences may be in part due to the small number of subjects in each category. Only three experienced and novice trackers and three males and females were used in any one of the studies. It is possible that larger numbers of subjects may yield different data. However, as noted earlier, the fairly simple nature of the tracking task used in these experiments may be responsible for the lack of significant experience effects. The transient AEP has been found to be

related to sex differences (Rodin et. al., 1965). However, the steady state AEP is quite different from the transient AEP and differences related to sex may be among those variables not influential in determining the steady state AEP.

The use of frequency analysis techniques on current and future data is indicated. Much of Regan's work with the steady state AEP is based upon frequency analysis of the data. In fact, Regan has stated that the primary frequency response and its harmonics may correspond to the various components of the transient AEP (Regan, 1977c) An harmonic component may be related to a particular phenomena while the primary and other harmonics are not (Regan, 1968b). This type of analysis might produce more robust effects that those found in the present report which are based for the most part upon the amplitude and phase lag of the fundamental frequency as recorded from the steady state AEP. Since the steady state AEP is basically a combination of the primary sine wave response at the stimulus frequency and its related harmonics frequency analysis is an ideal "method" of analysis.

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